sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.02.02.01	Inner HCAL prototype v1

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

This work package consists of all activities and materials needed to build a working prototype of the Inner Hadronic Calorimeter. The deliverable resulting from this work is an approximately 5x5 cell hadronic calorimeter complete with scintillator tiles with embedded wavelength shifting fiber coupled to silicon photomultipliers, preamps, and cables to the digitizer system. The resulting calorimeter prototype will be capable of being coupled to the digitizer system being developed for sPHENIX (which is not part of the technical scope of this WBS line). The output from the preamplifiers will be capable of detecting signals from minimum ionizing cosmic ray muons traversing the scintillator up to the energy deposition expected from a 60 GeV pion or proton. Provision will be made for LED flashers on every electronic channel which can be used to assess the health of the signal chain. The prototype will include provision for mechanical support in a beamline as well as any rigging fixtures which may be required. Design of electronics and cabling for this prototype are not part of the technical scope, but are provided by the calorimeter electronics design and prototyping tasks.

The test program will consist of testing with an LED flasher system and cosmic ray triggers. Operation in a beamline, most likely the Fermilab Test Beam Facility, will be carried out in concert with the Electromagnetic Calorimeter and Outer HCAL prototypes.

WORK STATEMENT:

- Mechanical design of absorber plates with provision for spacers providing clearance for insertion of scintillator tiles.
- Procurement of absorber plates.
- Mechanical design of scintillator tiles including routing of WLS fiber and provision for light collection to silicon photomultipliers.
- Procurement of scintillator tiles.
- Specification and design of light collector and silicon photomultiplier support with

connection to preampliers.
- Procurement of light collector components and coupling to scintillator tiles.
- Design, procurement, and construction of light tight and protective enclosure for calorimeter.

All design work needed to fabricate a prototype calorimeter is captured by this WBS line. A rather minimal amount of engineering is expected to be required because the prototype is relatively small.

Procurement of all the mechanical components of the prototype calorimeter is captured by this WBS item.

sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.02.02.02	Inner HCAL prototype v2

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

This work package consists of all activities and materials needed to build a working prototype of the Inner Hadronic Calorimeter. The deliverable resulting from this work is an approximately 5x5 cell hadronic calorimeter complete with scintillator tiles with embedded wavelength shifting fiber coupled to silicon photomultipliers, preamps, and cables to the digitizer system. The resulting calorimeter prototype will be capable of being coupled to the digitizer system being developed for sPHENIX (which is not part of the technical scope of this WBS line). The output from the preamplifiers will be capable of detecting signals from minimum ionizing cosmic ray muons traversing the scintillator up to the energy deposition expected from a 60 GeV pion or proton. Provision will be made for LED flashers on every electronic channel which can be used to assess the health of the signal chain. The prototype will include provision for mechanical support in a beamline. Design of electronics and cabling for this prototype are not part of the technical scope, but are provided by the design and prototyping tasks.

This WBS line differs from the Inner HCAL v1 prototype insofar as it allows testing near the maximum pseudorapidity subtended by the calorimeter module, i.e., near $\eta \sim 1$, equivalent to a polar angle of about 40°. It may be possible to reconfigure the absorber needed for the v1 prototype to accomplish this goal by replacing the scintillator tiles.

The test program will consist of testing with an LED flasher system and cosmic ray triggers. Operation in a beamline, most likely the Fermilab Test Beam Facility, will be carried out in concert with the Electromagnetic Calorimeter and Outer HCAL prototypes.

WORK STATEMENT:

- Mechanical design of absorber plates with provision for spacers providing clearance for insertion of scintillator tiles.

- Procurement of absorber plates.
- Mechanical design of scintillator tiles including routing of WLS fiber and provision for light collection to silicon photomultipliers.
- Procurement of scintillator tiles.
- Specification and design of light collector and silicon photomultiplier support with connection to preampliers.
- Procurement of light collector components and coupling to scintillator tiles.
- Design, procurement, and construction of light tight and protective enclosure for calorimeter.
- Attachment of preamplifier modules and cables to bring signals to the digitizer system.

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sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.02.02.03	Inner HCAL preproduction prototype

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

This work package consists of all activities needed to design, procure, and manufacture a full sized prototype sector the Inner Hadronic Calorimeter. A sector will be one of 32 sectors which will comprise the Inner HCAL. The deliverable for this WBS item will be a full sized sector populated partially with scintillating tiles (a minimum of once tower, with as many as six towers covering one half of the rapidity and one slice of azimuthal angle) that can be used to make mechanical measurements of the sector, develop handling and manufacturing techniques, and demonstrate cable management and light tighting methodology.

Development of handling techniques and lifting fixtures for transport and storage.

The testing will consist of measurements of the mechanical deformations of the structure and LED and cosmic ray tests of the active towers.

WORK STATEMENT:

- All mechanical design of a module necessary to install it in sPHENIX consistent with the Infrastructure and Installation task is contained in this WBS line. Installation tooling is to be produced as part of the Infrastructure and Installation task.
- Preparation of lifting fixtures, support tables, and workspace needed both for assembly and testing is captured here.
- All activities needed to procure the absorber and any fixtures or devices needed to construct a module are contained in this WBS line. Thus, all design effort needed to create production ready drawings are deliverable.
- Since it is unlikely that the full sized prototype module could be beam tested, it may not be necessary to populate it fully with scintillator tiles. However, a minimum of one complete calorimeter cell (five tiles) should be populated, and provision should be made for adding additional tiles for mechanical and cosmic ray testing.

sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.02.01	Inner HCAL design

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

The Inner HCAL detector will be fully designed mechanically, both the absorber plates, constructed out of materials which have been demonstrated to have minimal effect on the 1.5 T magnetic field, and the scintillator tiles which are inserted into slots between the tapered steel plates.

WORK STATEMENT:

- Mechanical design of the inner HCAL, including interfaces with the Installation and Infrastructure task, which will provide mechanical support and assembly methodology for the Inner HCAL inside the solenoid will be fully captured by this WBS item.
- Analysis of the structure including gravitational loading and static and dynamic forces on the structure from the magnetic field.
- Design of cable management for signal cables exiting the detector volume.
- Design of the scintillator tiles, including whatever components are needed to connect the SiPM's to the tiles.
- Preparation of all documentation for design and safety reviews.
- Carry out design and safety reviews for the Inner HCAL.

sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.02.03.01	Inner HCAL module production

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

Inner HCAL module production consists of all activities needed to take the Inner HCAL design (completed under WBS item 1.06.02.01) and complete construction of 32 modules that can be delivered to the sPHENIX Assembly Hall for installation in the detector. Since design activities will be complete, this WBS line captures the effort needed to actually produce the modules, including procurement of the absorber, procurement of any mechanical parts needed to assemble and strengthen the absorber into a rigid structure, and manufacture of any additional handling fixtures needed to construct the modules. Procurement and delivery of scintillator tiles with embedded WLS fiber designed under WBS 1.06.01.01 is contained in this WBS line, as well as production of any assemblies needed to couple the photodetectors to the scintillating tiles.

WORK STATEMENT:

- Procurement and acceptance verification of parts needed to construct the Inner HCAL modules, including
  - Absorber plates
  - Scintillating tiles
  - Light collection hardware
  - Cable management hardware
- Preparation of workspaces need for assembly in Inner HCAL modules
- Preparation of any storage needed while modules await assembly

sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.02.03.02	Inner HCAL module assembly

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

This WBS line is meant to capture all the activities needed to take the Inner HCAL module components procured under WMS 1.06.02.03.01 and assemble them into operational modules which can be tested as part of WBS 1.06.02.03.03. the major part of the work will consist of assembling parts (absorber, scintillator tiles, light collection and SiPM's) and providing workspace for acceptance testing of the modules.

WORK STATEMENT:

- Stacking of absorber in a horizontal orientation in several stations of assembly.
- Insertion of scintillator tiles with light collection assemblies already integrated.
- Connection of light collectors to preamplifier cables.
- Connection of preamplifiers to controller modules (providing temperature measurement and compensation.
- Connection of LED pulser system.
- Cable management and preparation for acceptance testing.
- Completing module construction with light-tight covers making each module individually capable of test.

sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.02.03.03	Inner HCAL module/testing/calibration/integration

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

Fully assembled Inner HCAL modules are tested and calibrated by the LED pulser system and with cosmic ray data. In order to accomplish this, the controller is powered an bias is supplied by the production bias supply. Measurements of the leakage currents from each calorimeter cell are made and recorded.

Acceptance criteria require that any bias current draw outside three sigma of the mean observed in the prototypes is investigated and repaired if necessary. Testing with the preamplifier test pulse and LED light pulser are used to verify that each channel is alive and that all five scintillator tiles are functional.

WORK STATEMENT:

- Connection of power, bias cables, communication, and signal cables to preamplifiers, and connection to one or more test racks of electronics.
- Measurement of bias current and debugging of any mis-connected photodetectors or light leaks.
- Measurement of LED pulses from each channel
- Setup of trigger counters for cosmic ray testing.
- Collection of cosmic ray data from all channels.
- Data logging and record keeping for each module.

sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.03.02.01	Outer HCAL prototype v1

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

This work package consists of all activities and materials needed to build a working prototype of the Outer Hadronic Calorimeter. The deliverable resulting from this work is an approximately 5x5 cell hadronic calorimeter complete with scintillator tiles with embedded wavelength shifting fiber coupled to silicon photomultipliers, preamps, and cables to the digitizer system. The resulting calorimeter prototype will be capable of being coupled to the digitizer system being developed for sPHENIX (which is not part of the technical scope of this WBS line). The output from the preamplifiers will be capable of detecting signals from minimum ionizing cosmic ray muons traversing the scintillator up to the energy deposition expected from a 60 GeV pion or proton. Provision will be made for LED flashers on every electronic channel which can be used to assess the health of the signal chain. The prototype will include provision for mechanical support in a beamline as well as any rigging fixtures which may be required. Design of electronics and cabling for this prototype are not part of the technical scope, but are provided by the calorimeter electronics design and prototyping tasks.

The test program will consist of testing with an LED flasher system and cosmic ray triggers. Operation in a beamline, most likely the Fermilab Test Beam Facility, will be carried out in concert with the Electromagnetic Calorimeter and Outer HCAL prototypes.

WORK STATEMENT:

- Mechanical design of absorber plates with provision for spacers providing clearance for insertion of scintillator tiles.
- Procurement of absorber plates.
- Mechanical design of scintillator tiles including routing of WLS fiber and provision for light collection to silicon photomultipliers.
- Procurement of scintillator tiles.
- Specification and design of light collector and silicon photomultiplier support with

connection to preampliers.
- Procurement of light collector components and coupling to scintillator tiles.
- Design, procurement, and construction of light tight and protective enclosure for calorimeter.

All design work needed to fabricate a prototype calorimeter is captured by this WBS line. A rather minimal amount of engineering is expected to be required because the prototype is relatively small.

Procurement of all the mechanical components of the prototype calorimeter is captured by this WBS item.

sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.03.02.02	Outer HCAL prototype v2

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

This work package consists of all activities and materials needed to build a working prototype of the Outer Hadronic Calorimeter. The deliverable resulting from this work is an approximately 5x5 cell hadronic calorimeter complete with scintillator tiles with embedded wavelength shifting fiber coupled to silicon photomultipliers, preamps, and cables to the digitizer system. The resulting calorimeter prototype will be capable of being coupled to the digitizer system being developed for sPHENIX (which is not part of the technical scope of this WBS line). The output from the preamplifiers will be capable of detecting signals from minimum ionizing cosmic ray muons traversing the scintillator up to the energy deposition expected from a 60 GeV pion or proton. Provision will be made for LED flashers on every electronic channel which can be used to assess the health of the signal chain. The prototype will include provision for mechanical support in a beamline. Design of electronics and cabling for this prototype are not part of the technical scope, but are provided by the design and prototyping tasks.

This WBS line differs from the Outer HCAL v1 prototype insofar as it allows testing near the maximum pseudorapidity subtended by the calorimeter module, i.e., near $\eta \sim 1$, equivalent to a polar angle of about 40°. It may be possible to reconfigure the absorber needed for the v1 prototype to accomplish this goal by replacing the scintillator tiles.

The test program will consist of testing with an LED flasher system and cosmic ray triggers. Operation in a beamline, most likely the Fermilab Test Beam Facility, will be carried out in concert with the Electromagnetic Calorimeter and Outer HCAL prototypes.

WORK STATEMENT:

- Mechanical design of absorber plates with provision for spacers providing clearance for insertion of scintillator tiles.

- Procurement of absorber plates.
- Mechanical design of scintillator tiles including routing of WLS fiber and provision for light collection to silicon photomultipliers.
- Procurement of scintillator tiles.
- Specification and design of light collector and silicon photomultiplier support with connection to preampliers.
- Procurement of light collector components and coupling to scintillator tiles.
- Design, procurement, and construction of light tight and protective enclosure for calorimeter.
- Attachment of preamplifier modules and cables to bring signals to the digitizer system.

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sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.03.02.03	Outer HCAL preproduction prototype

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

This work package consists of all activities needed to design, procure, and manufacture a full sized prototype sector the Outer Hadronic Calorimeter. A sector will be one of 32 sectors which will comprise the Outer HCAL. The deliverable for this WBS item will be a full sized sector populated partially with scintillating tiles (a minimum of once tower, with as many as six towers covering one half of the rapidity and one slice of azimuthal angle) that can be used to make mechanical measurements of the sector, develop handling and manufacturing techniques, and demonstrate cable management and light tighting methodology.

Development of handling techniques and lifting fixtures for transport and storage.

The testing will consist of measurements of the mechanical deformations of the structure and LED and cosmic ray tests of the active towers.

WORK STATEMENT:

- All mechanical design of a module necessary to install it in sPHENIX consistent with the Infrastructure and Installation task is contained in this WBS line. Installation tooling is to be produced as part of the Infrastructure and Installation task.
- Preparation of lifting fixtures, support tables, and workspace needed both for assembly and testing is captured here.
- All activities needed to procure the absorber and any fixtures or devices needed to construct a module are contained in this WBS line. Thus, all design effort needed to create production ready drawings are deliverable.
- Since it is unlikely that the full sized prototype module could be beam tested, it may not be necessary to populate it fully with scintillator tiles. However, a minimum of one complete calorimeter cell (five tiles) should be populated, and provision should be made for adding additional tiles for mechanical and cosmic ray testing.

sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.03.01	Outer HCAL design

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

The Outer HCAL detector will be fully designed mechanically, both the absorber plates, constructed out of materials which have been demonstrated to have minimal effect on the 1.5 T magnetic field, and the scintillator tiles which are inserted into slots between the tapered steel plates.

WORK STATEMENT:

- Mechanical design of the Outer HCAL, including interfaces with the Installation and Infrastructure task, which will provide mechanical support and assembly methodology for the Outer HCAL inside the solenoid will be fully captured by this WBS item.
- Analysis of the structure including gravitational loading and static and dynamic forces on the structure from the magnetic field.
- Design of cable management for signal cables exiting the detector volume.
- Design of the scintillator tiles, including whatever components are needed to connect the SiPM's to the tiles.
- Preparation of all documentation for design and safety reviews.
- Carry out design and safety reviews for the Outer HCAL.

sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.03.03.01	Outer HCAL module production

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

Outer HCAL module production consists of all activities needed to take the Outer HCAL design (completed under WBS item 1.06.02.01) and complete construction of 32 modules that can be delivered to the sPHENIX Assembly Hall for installation in the detector. Since design activities will be complete, this WBS line captures the effort needed to actually produce the modules, including procurement of the absorber, procurement of any mechanical parts needed to assemble and strengthen the absorber into a rigid structure, and manufacture of any additional handling fixtures needed to construct the modules. Procurement and delivery of scintillator tiles with embedded WLS fiber designed under WBS 1.06.01.01 is contained in this WBS line, as well as production of any assemblies needed to couple the photodetectors to the scintillating tiles.

WORK STATEMENT:

- Procurement and acceptance verification of parts needed to construct the Outer HCAL modules, including
  - Absorber plates
  - Scintillating tiles
  - Light collection hardware
  - Cable management hardware
- Preparation of workspaces need for assembly in Outer HCAL modules
- Preparation of any storage needed while modules await assembly

sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.03.03.02	Outer HCAL module assembly

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

This WBS line is meant to capture all the activities needed to take the Outer HCAL module components procured under WMS 1.06.02.03.01 and assemble them into operational modules which can be tested as part of WBS 1.06.02.03.03. the major part of the work will consist of assembling parts (absorber, scintillator tiles, light collection and SiPM's) and providing workspace for acceptance testing of the modules.

WORK STATEMENT:

- Stacking of absorber in a horizontal orientation in several stations of assembly.
- Insertion of scintillator tiles with light collection assemblies already integrated.
- Connection of light collectors to preamplifier cables.
- Connection of preamplifiers to controller modules (providing temperature measurement and compensation.
- Connection of LED pulser system.
- Cable management and preparation for acceptance testing.
- Completing module construction with light-tight covers making each module individually capable of test.

sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.03.03.03	Outer HCAL module/testing/calibration/integration

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

Fully assembled Outer HCAL modules are tested and calibrated by the LED pulser system and with cosmic ray data. In order to accomplish this, the controller is powered an bias is supplied by the production bias supply. Measurements of the leakage currents from each calorimeter cell are made and recorded.

Acceptance criteria require that any bias current draw outside three sigma of the mean observed in the prototypes is investigated and repaired if necessary. Testing with the preamplifier test pulse and LED light pulser are used to verify that each channel is alive and that all five scintillator tiles are functional.

WORK STATEMENT:

- Connection of power, bias cables, communication, and signal cables to preamplifiers, and connection to one or more test racks of electronics.
- Measurement of bias current and debugging of any mis-connected photodetectors or light leaks.
- Measurement of LED pulses from each channel
- Setup of trigger counters for cosmic ray testing.
- Collection of cosmic ray data from all channels.
- Data logging and record keeping for each module.

sPHENIX	01/26/2015	E. Kistenev, J. Lajoie, J. Haggerty

4. WBS Element Code	5. WBS Element Title
1.06.01	HCAL Management

6. Index Line Number:	7. Revision Number and Authorization:	8: Rev. Date

9. Approved Changes

9. Element Task Description

COST CONTENT:

TECHNICAL SCOPE:

Management of the HCAL system contains oversight of the construction project as well as coordination with the experimental collaboration and making certain that the as-built detector configuration is capable of carrying out the physics program of the collaboration. Preparation of cost and schedule data for design, safety, and installation reviews as well as for monitoring the progress of the construction is captured in this WBS.

WORK STATEMENT:

- Preparation of documentation for reviews.
- Preparation of cost and schedule data.